

The background image shows a large concrete dam with water cascading over its spillways. In the foreground, a large, light-colored cylindrical pipe or culvert runs diagonally across the frame, partially obscured by dense vegetation and reeds. The scene is set in a natural, wooded environment.

Kleinschmidt

Energy & Water Resource Consultants

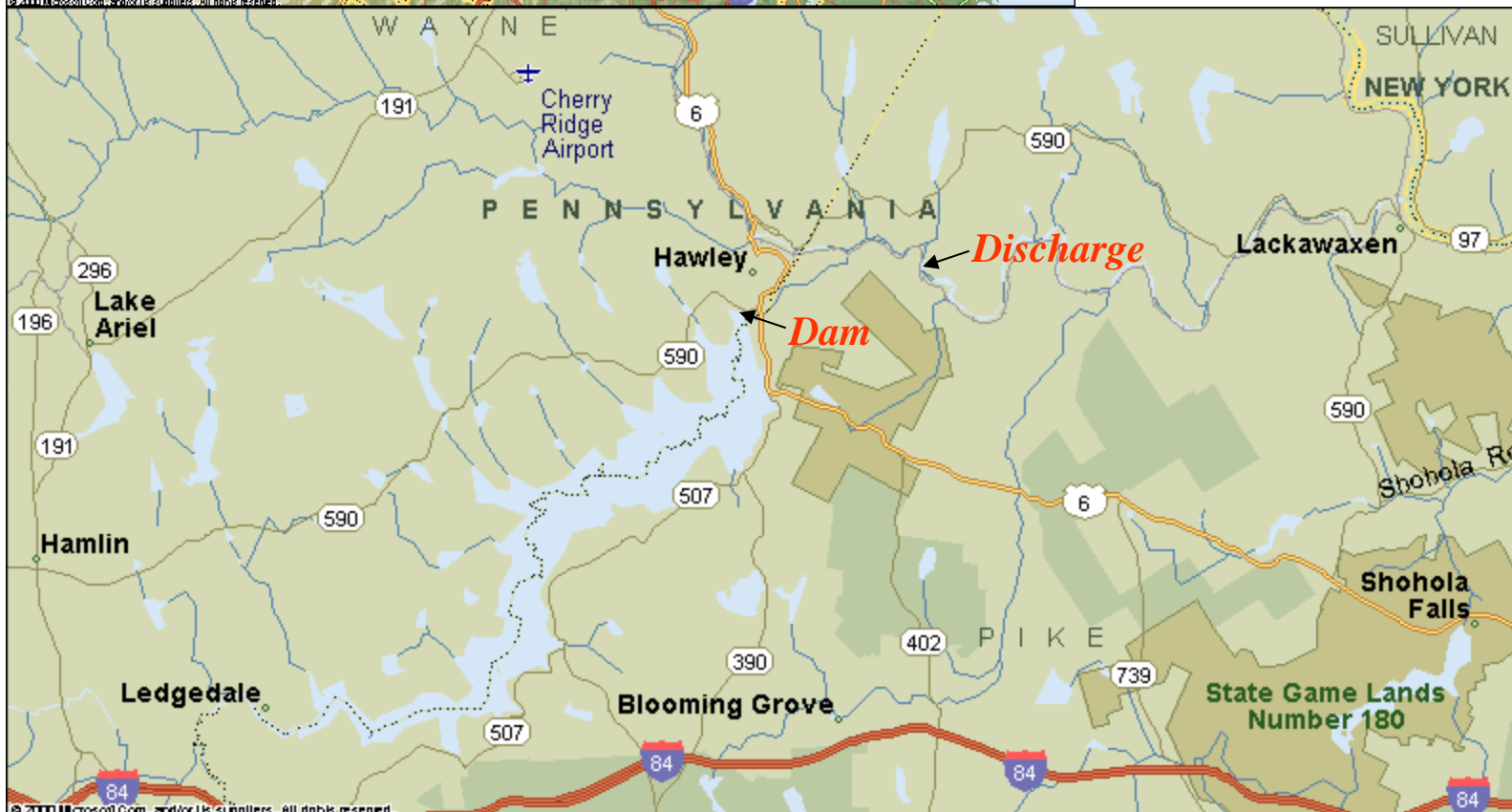
Review of Physical and Chemical Remediation Techniques for Hydrogen Sulfide Abatement in a Bottom-Withdrawal Hydropower Reservoir

John R. Shuman, Bradley R. Shultz & Timothy J. Oakes

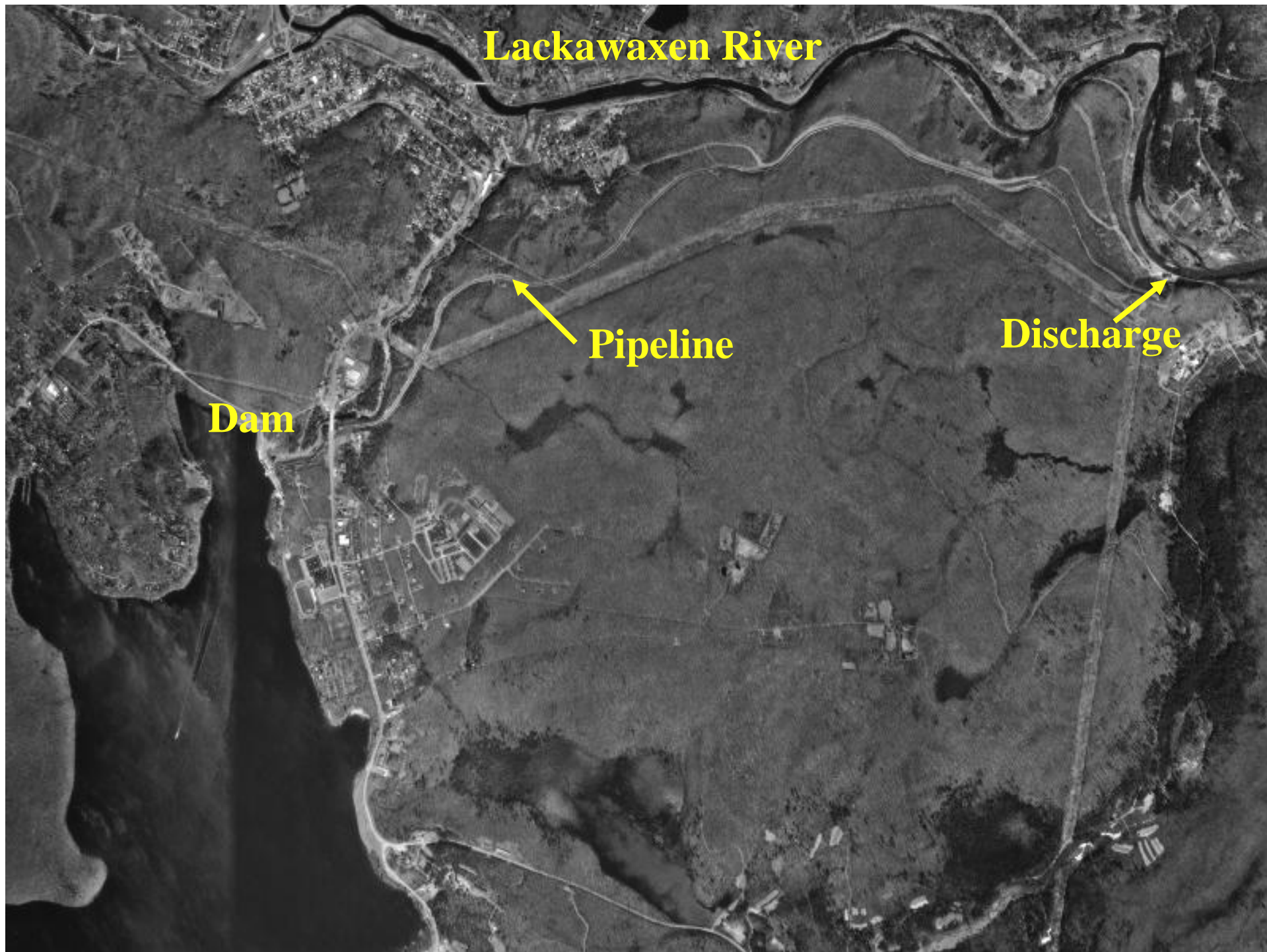


Lake Wallenpaupack:

- 5,700 acres
- 116,650 acre-feet*
- 40 ft mean depth
- pipeline 3.5 mi long



* usable storage

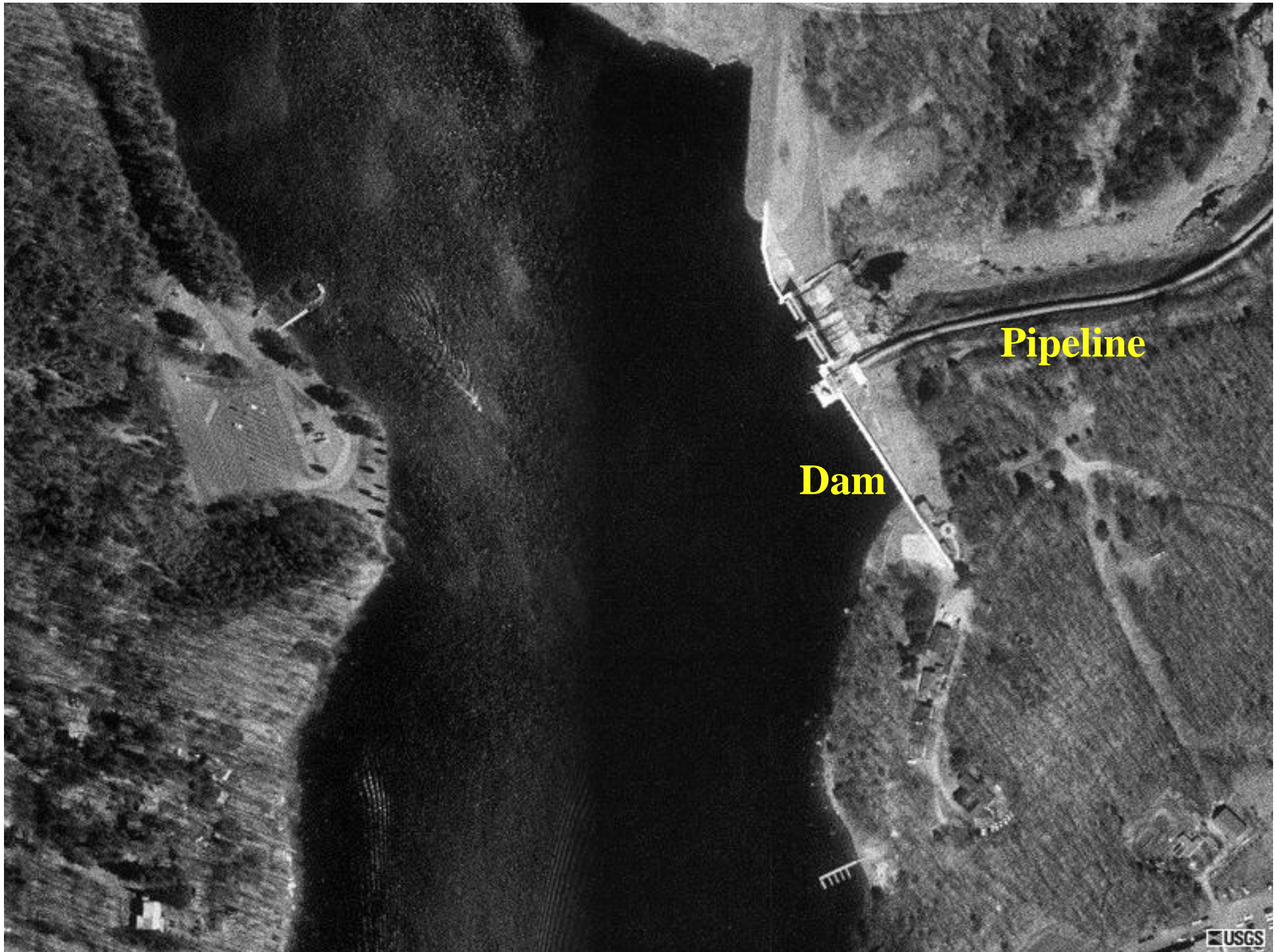


Lackawaxen River

Pipeline

Discharge

Dam



Pipeline

Dam

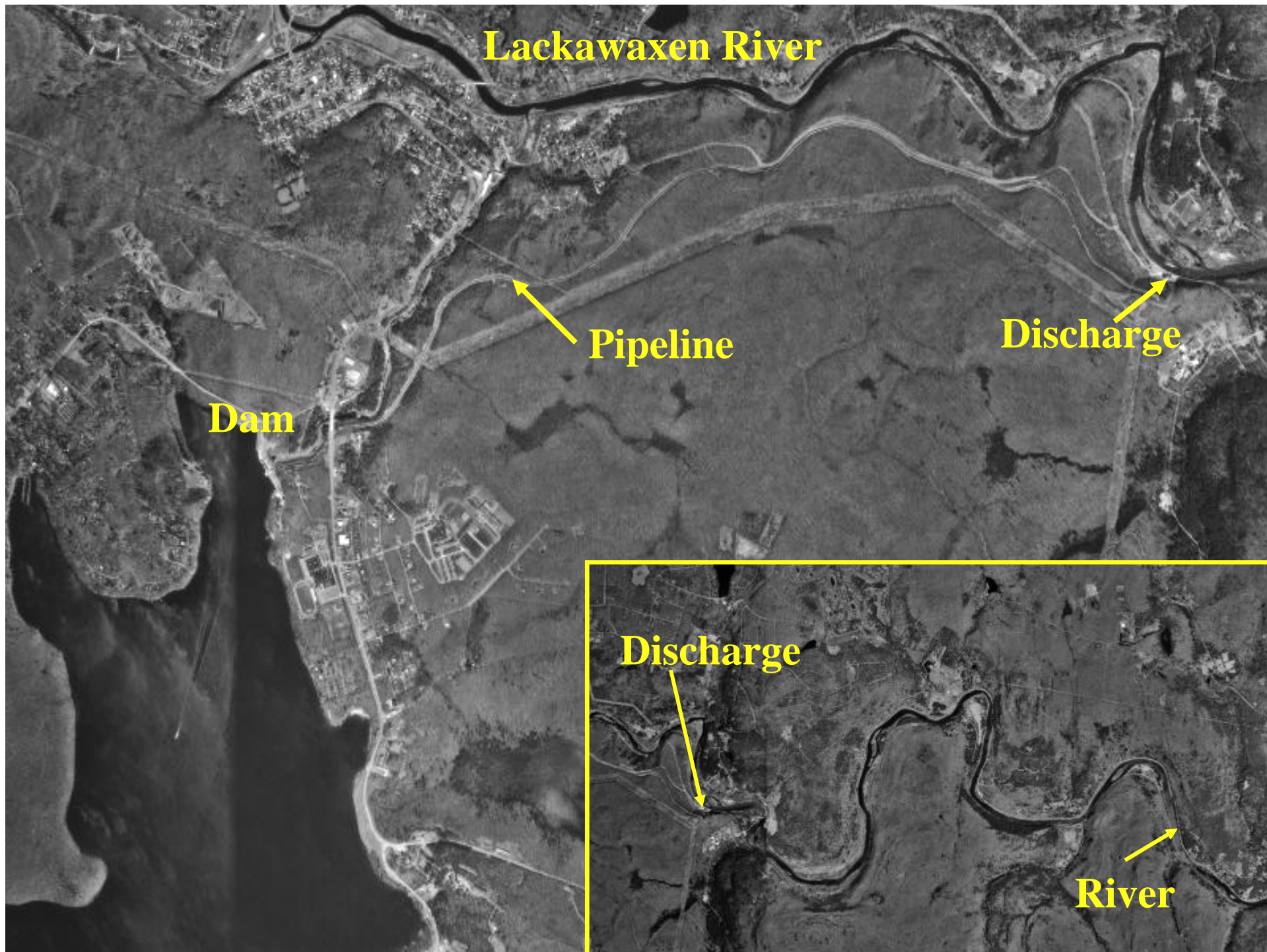


River

Pipeline →

**Power
Plant**





Lackawaxen River

Pipeline

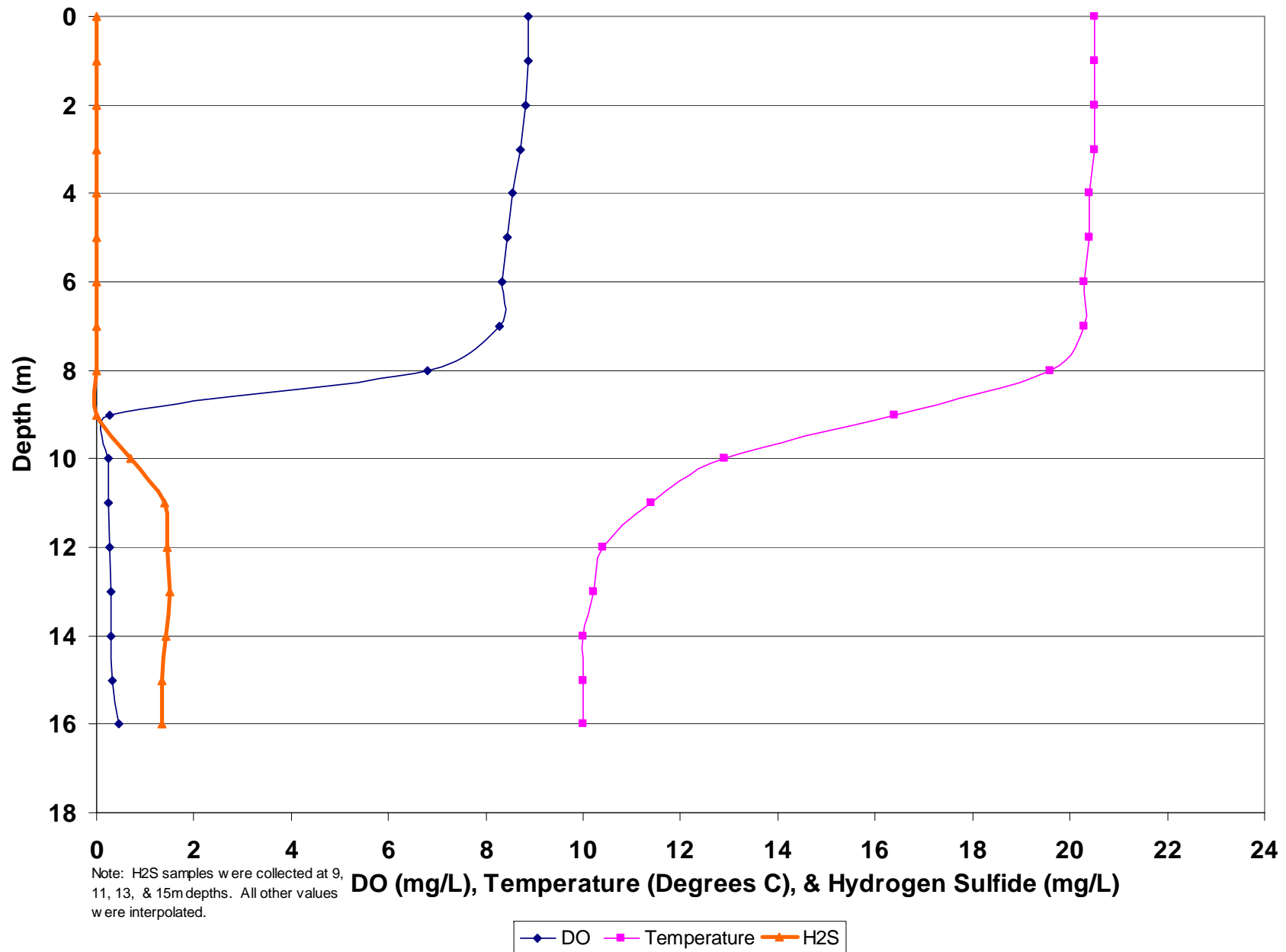
Discharge

Dam

Discharge

River

Lake Profile @ Wilsonville 9/25/01



Nature of the Problem

- Sulfate sources: precipitation, inflow, septics
- Hypolimnetic anoxia during summer - enhanced by organic matter loading
- Sulfate reduced to hydrogen sulfide during anoxia
- Hypolimnetic withdrawal during operation (supports coldwater fishery) - results in tailrace degassing of H_2S
- Need to either prevent formation or enhance removal of H_2S to minimize odor problem

Expert Panel Gathering

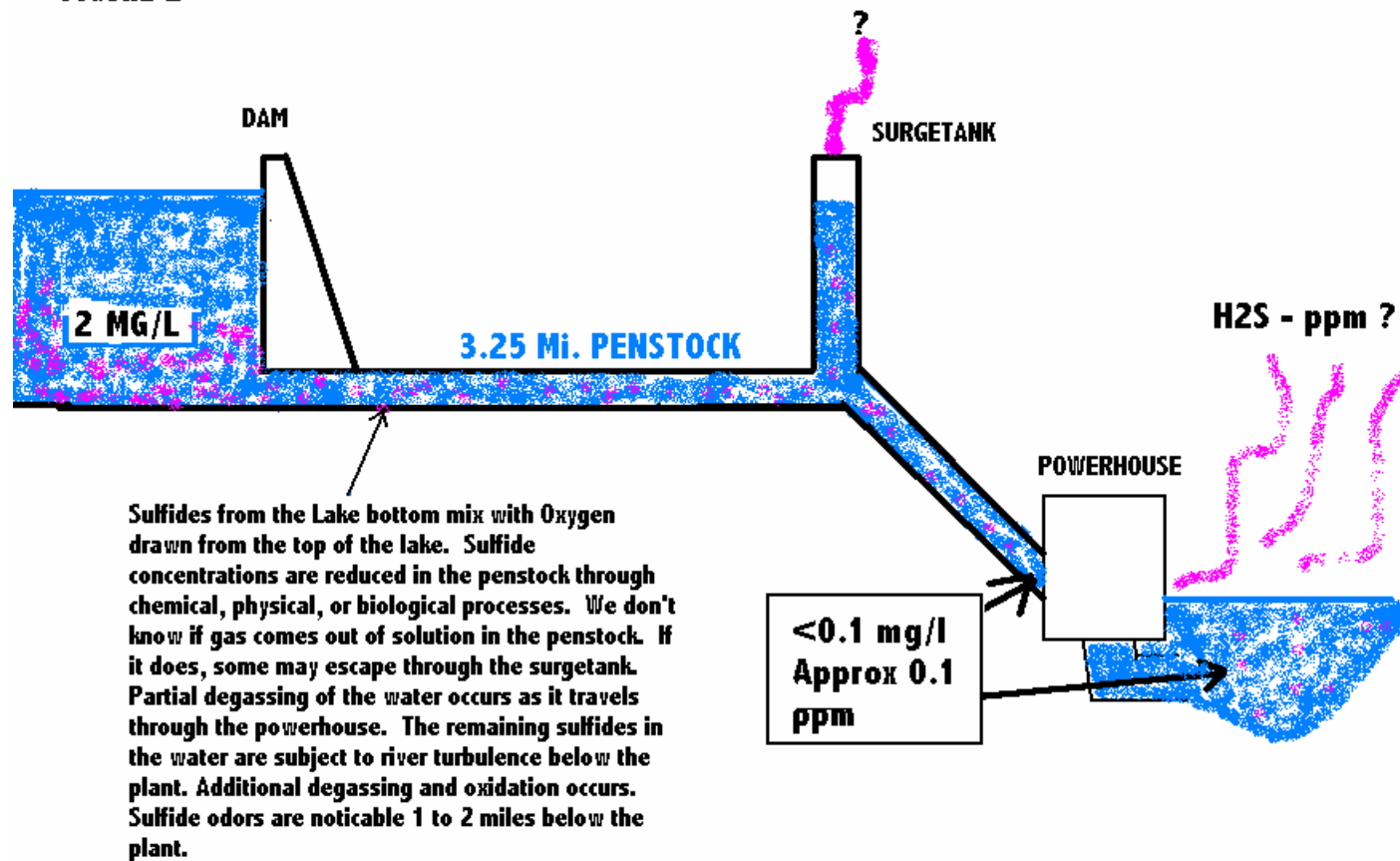
- Robert Wetzel, Univ. North Carolina
- Robert Gambrell, Louisiana State
- Steve Ashby, COE Vicksburg
- George Luther, Univ. Delaware
- Richard Ruane, Reservoir Env. Mgmt., Inc.
- Forest Dierberg, DB Environmental, Inc.
- Yuefeng Xie, Penn State Harrisburg
- Frank Browne, FX Browne, Inc.

Objectives

- Short-Term:
 - In-lake or in-pipeline H₂S control
 - prevent formation
 - enhance oxidation or precipitation
- Long-Term:
 - Watershed management
 - reduce sulfate inputs
 - reduce organic matter loading

Current removal of sulfide

FIGURE 2



Pipeline H₂S Removal Techniques



In-Pipe Approaches

- Enhance mixing
 - Immediate dilution effects
 - Longer time-of-travel for oxidation by DO
- Promote oxidation by dissolved oxygen
 - Air bubbler at pipeline intake
 - Add oxygen to air bubbler
- pH modification, chemical oxidation
 - Increase pH (form HS^- , faster oxidation)
 - Add H_2O_2 or Cl^- to oxidize H_2S

H₂S Oxidation by Dissolved Oxygen

May be too slow for the pipeline

<i>Time (min)</i>	<i>Sulfide (mg/L)</i>
0	0.23
1	0.23
3	0.23
5	0.23
10	0.22
30	0.20

DO = 7.6

pH Modification

Chemical Oxidation

HS^- predominant at $\text{pH} > 7.0$ (no odor)

S_8 produced at $\text{pH} < 7$ with oxidation

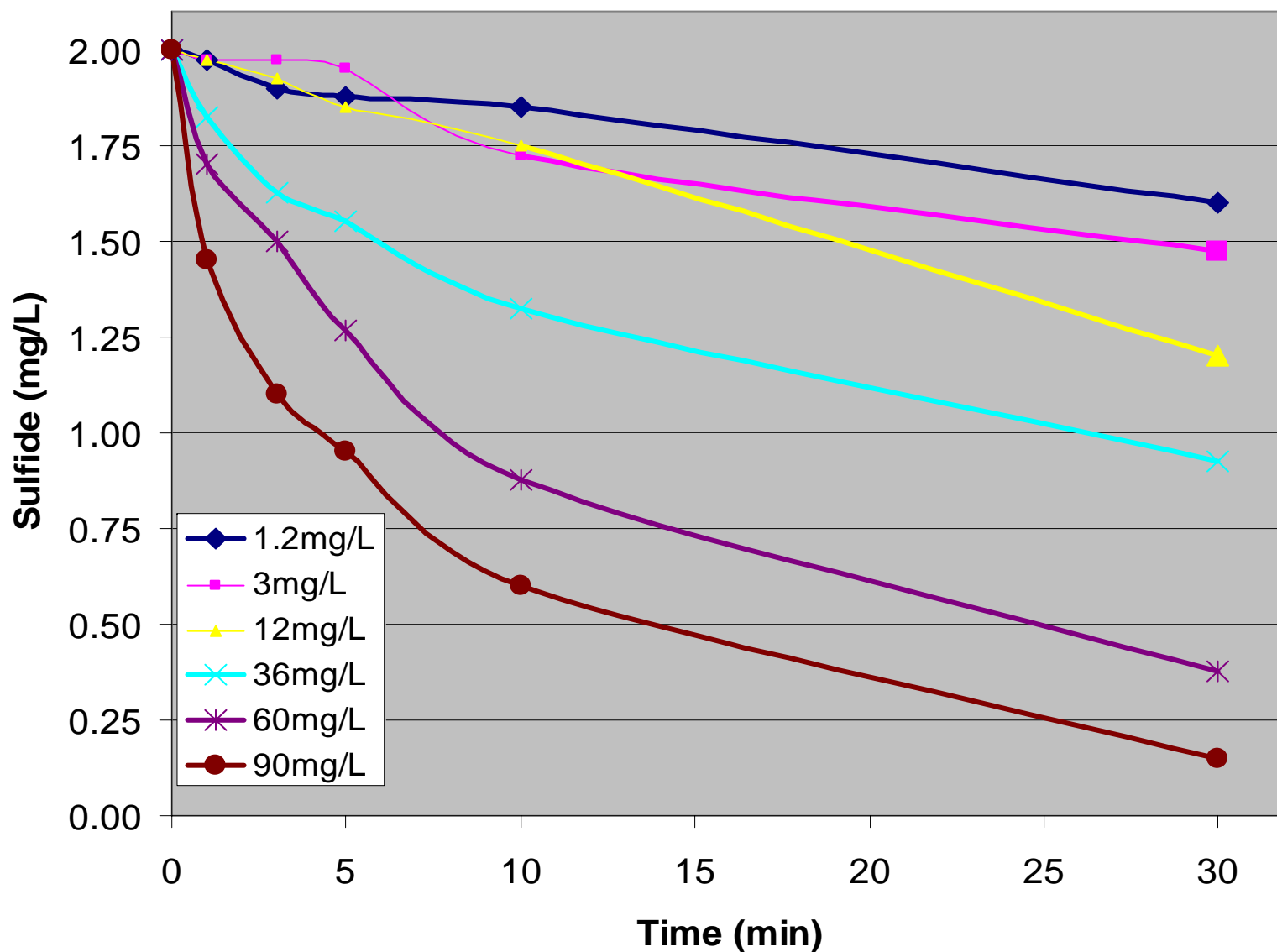
4x H_2O_2 needed at $\text{pH} > 7.5$

2:1 mole ratio H_2O_2 recommended at $\text{pH} = 7$

15-minute H_2O_2 residence time suggested

Oxidants H_2O_2 and NaOCl tested

H_2O_2 as Oxidant with Lake Water



NaOCl as Oxidant with Lake Water

30-minute exposure

Concentrations in mg/L

pH = 6.58

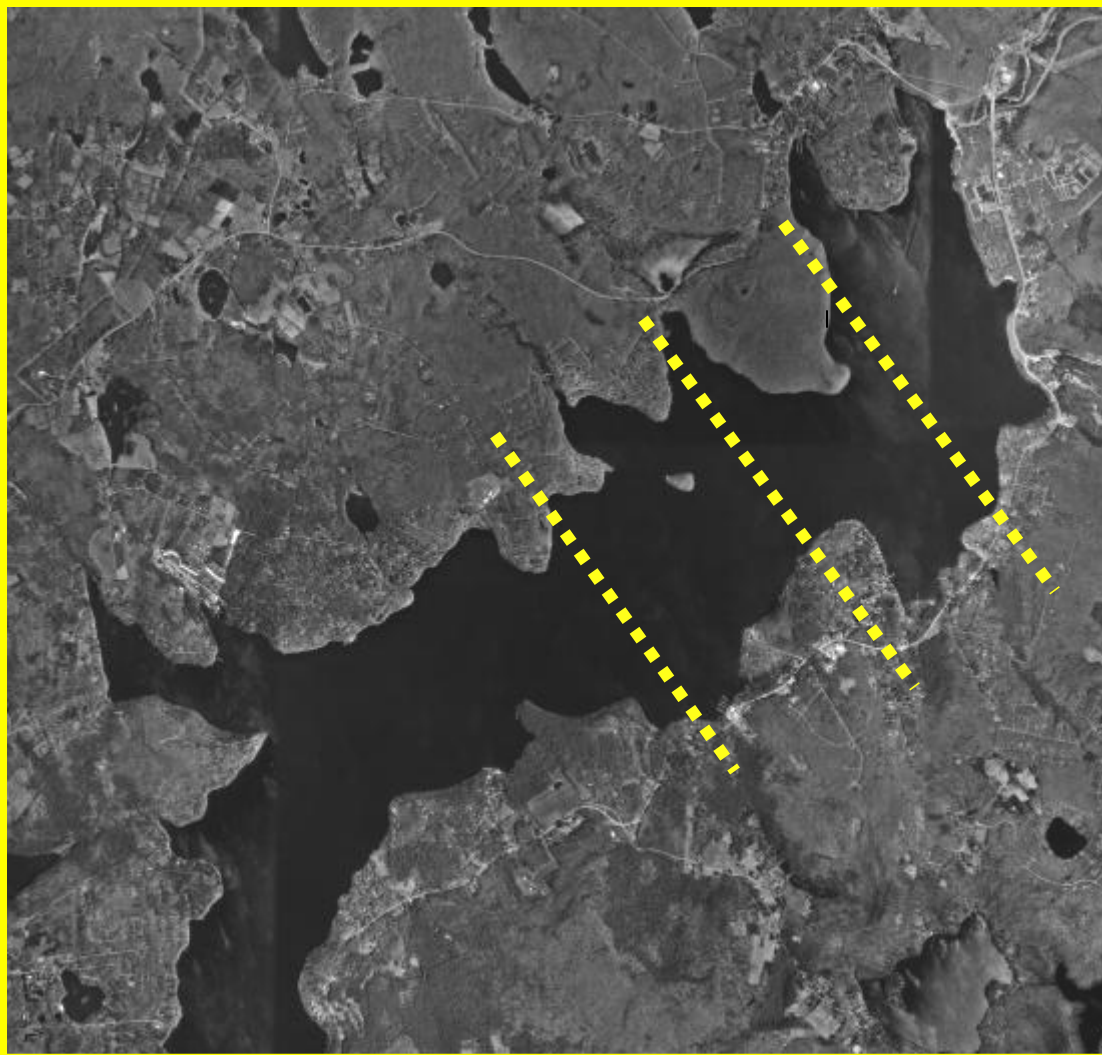
NaOCl	Initial H ₂ S	Final H ₂ S	Free Cl ⁻
1	1.725	0.875	0
2	1.650	0.750	0
5	1.825	0.625	0



In-Lake H_2S Remediation Techniques

- Hypolimnetic Aeration
- Iron Addition
- pH Modification

Hypolimnetic Aeration

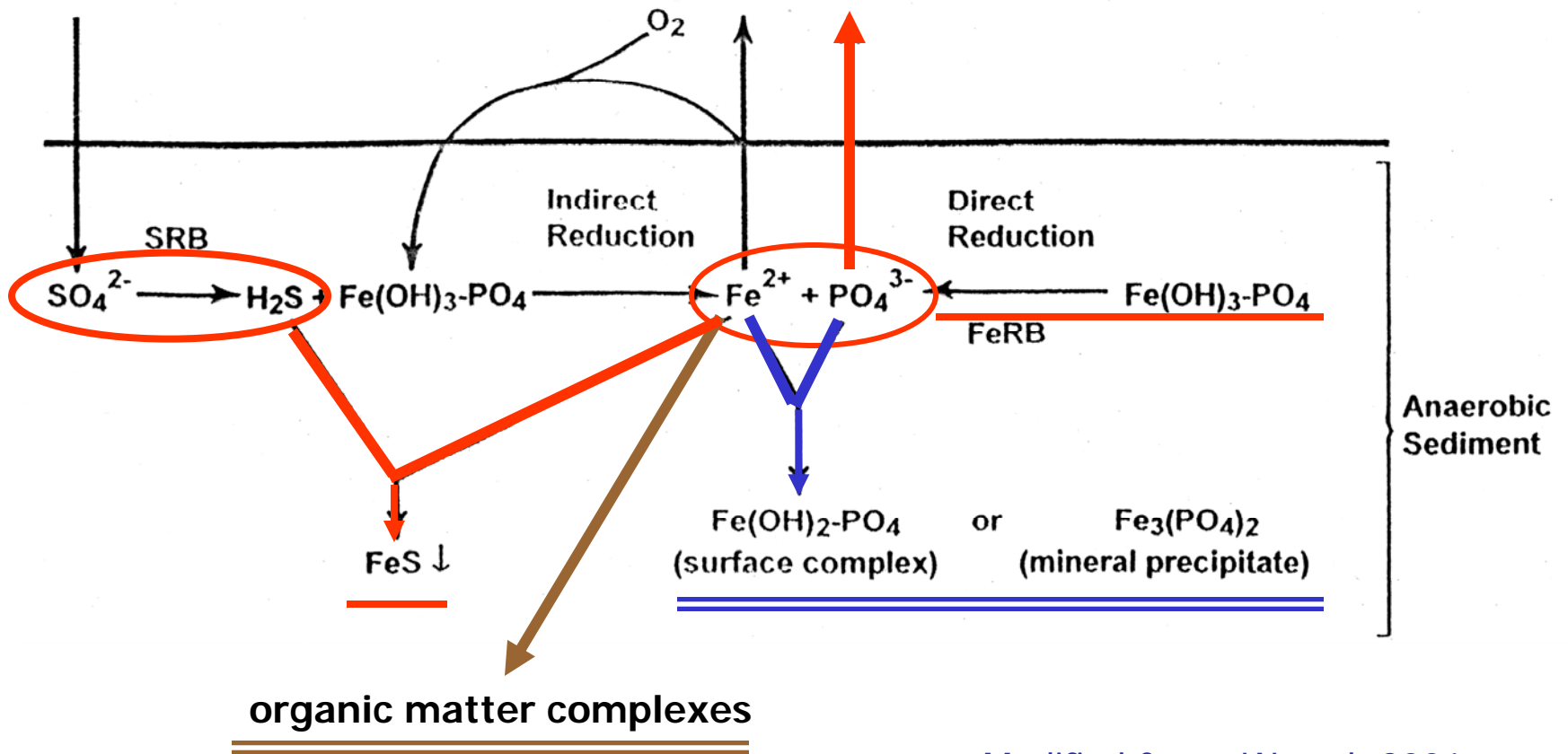


- Maintain thermocline (cold water)
- Enhance oxidation of H_2S by oxygen
- Lake volume to treat (oxid. rates)
- Avoid nutrient upwelling

In-Lake Iron Addition

- Under oxic conditions:
 - Fe^{2+} oxidized to Fe^{3+}
 - Fe^{3+} can oxidize H_2S to S_8 at $\text{pH} > 6$
- Under anoxic conditions:
 - Fe^{3+} is reduced to Fe^{2+}
 - Fe^{2+} and H_2S can form FeS_{aq} and $\text{FeS}_2\downarrow$
 - PO_4^{3-} can be released with insufficient Fe

Sulfur - Iron- Phosphorus Cycle Interactions



Modified from: Wetzel, 2001

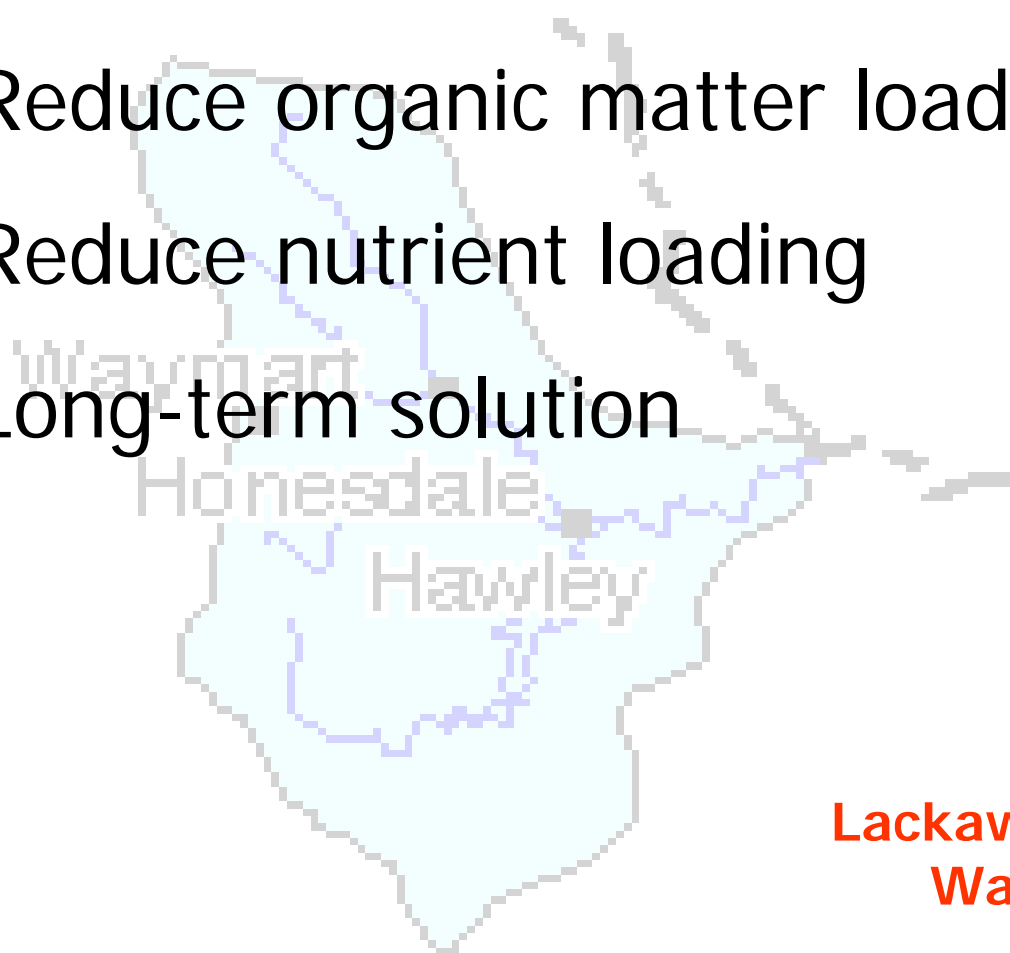
Modified from: Roden and Edmonds, 1997

In-Lake pH Modification

- Add limerock in area near intake:
 - to increase pH to about 7.5
 - favors HS^- over H_2S at higher pH's
 - HS^- predominant at $\text{pH} > 7.0$ (no odor)
- Treatment area and longevity unknown

Watershed Management Efforts

- Reduce sulfate/sulfur input
- Reduce organic matter loading
- Reduce nutrient loading
- Long-term solution



**Lackawaxen River
Watershed**

Summary of Techniques

- In-Pipe Remediation:
 - Enhance mixing
 - Promote oxidation by oxygen
 - pH modification
 - Chemical oxidation (H_2O_2 or NaOCl)
- In-Lake Remediation:
 - Hypolimnetic aeration
 - Iron addition
 - pH modification
- Watershed Remediation
 - Nutrient and organic matter reductions
 - Sulfate/sulfur loading reductions